Bushings

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DEVELOPMENT OF A 2050 KV BIL BUSHING

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The present trend toward larger power systems and interconnection of existing systems, to transmit larger amounts of power, has dictated the use of higher voltages for more efficient power transmission. Voltages of 460 KV or higher are expected to be in use in the United States within the next decade.

These facts prompted the establishment of the Extra High Voltage Project.[1] This paper describes the engineering and manufacturing problems associated with building the first sample of the extra high voltage bushings required for this project and presents test data obtained from this sample.

The data obtained indicates that bushings, for the highest system voltages expected in this country in the next decade, can be built using processes and materials presently available. The standard center-clamped construction with oil impregnated paper internal insulation is retained in this sample bushing.

DESIGN

The test values desired for this bushing, as shown in Table I, were selected by extrapolation using 2000 KV BIL as the base for selecting other test values. Most bushing test values have a relatively straight line relation with BIL.

Table I

Design Test Values

	60 Cycle		Impulse	
Bil Kv	One Minute Withstand Kv	10-Sec. Wet Withstand Kv	Chopped Wave Crest Kv	Front of Wave Crest Kv
2000	1050	865	2300	2520

The length of top porcelain compared to BIL for lower voltage bushings is relatively uniform below 825 KV BIL but increases slightly at each step above 825 KV. The largest bushing which the company the author is associated with had built and tested is 1550 KV BIL. This bushing has a top porcelain 10 feet 10 inches high and has withstood test values above the 1550 KV BIL level. Using the ratio of length to BIL for this bushing and extending it to 2000 KV BIL shows a porcelain length of 14 feet 1 inch. The top porcelain for the 2050 KV BIL bushing is 14 feet 2 inches long.

The length of bottom porcelain compared to BIL is more regular for all ratings; being between 29 KV and 30 KV BIL per inch of porcelain length. A length of 6 feet was selected for the bottom porcelain of this bushing. This is approximately 28 KV BIL per inch of bottom end length.

The dimensions of the internal insulation are limited by the method of manufacture of the core. Retaining our normal method of manufacture was considered desirable. This consists of a single web of paper wound on the center conductor with stress equalizers slightly shorter than the paper width. The total length of core insulation is limited to the widest paper that can be obtained from a manufacturer of electrical grade paper. Since the widest paper available for this bushing was 185 inches, the minimum axial insulation length at each end was desired.

A check of some of the special designs with short bottom ends indicated a 50 inch length should be adequate for this bushing. The problem then became one of how to locate this end grading inside the bottom porcelain to obtain as uniform voltage distribution over the porcelain surfaces as possible.

An electrolytic flux plot was made using a model of a standard bushing but moving the pattern of the core insulation stress equalizer ends. This plot indicated that shortening the extension of the ground electrode into the bottom porcelain did not change the axial distribution of voltage along the porcelain significantly. Shortening the total extension of the electrode end pattern increased the radial voltage gradient near the bottom washer, however this did not appear to be critical.

Short extensions of insulation into top porcelains has been tried many times on different size bushings to obtain a desired voltage distribution over the exterior of the porcelain. Extensions as low as 50% of the porcelain height have been tried on lower voltage bushings. This is probably more critical in extra high voltage bushings however, and the longest stress equalizer in the core for this bushing extends into the top porcelain 110 inches or 65% of the porcelain height.

These lengths of insulation in each porcelain permitted only 18 inches for the total length of the bushing support. The total length of the assembled bushing is 25 feet 7 inches.

The diameter of the core insulation is not limited by manufacturing facilities. Therefore a relatively low radial stress limit was chosen to partially offset the short axial lengths. The diameter of the core insulation, including the C_2 or tap capacitance, is 28-1/2 inches.

MANUFACTURE

A bushing core winding machine equipped with shields for spray application of conducting equalizers was used to wind the core for this bushing. Small amounts of adhesive were added at constantly varying axial locations while the core was being wound. The same adhesive was applied continuously across the entire width of paper for several turns at the termination of the wind to provide a mechanically strong outer shell on the core. The adhesive spotted throughout the wind adds to the resistance of the paper against slipping or telescoping without interfering with oil impregnation of the structure. The outer shell is required for protection during handling of the core and for the supporting structure added at assembly of the bushing. The completed core is shown in Figure No. 1.

The top porcelain of this bushing is exceptional as there are three separate sections with ground parallel surfaces at each end of each section. These are assembled with nitrile rubber gaskets between each section and there is a slight overhang on the upper section at the two gasketed joints.

This bushing is of center clamped construction with spring loading to maintain a relatively high percentage of the original clamping force when the center tube expands at higher temperatures. The springs are compressed; gaskets deflected; and core tube loaded in tension when the center clamping force is applied by hydraulic jacks. The jack assemblies available were adequate but a new pressure gauge was required to measure the 30 tons of clamping force specified for this bushing.

The large amount of insulation on the core increases the need for auxilliary support in the bushing assembly. Four core supports, made of 1/8 inch thick pressboard strips riveted together, are used at the bottom end of the core. These are cut to fit the contour of the steps on the lower end of the core and are cut to length, to rest on the bottom washer. They also contact the bottom porcelain at various points along their length. These supports are cut to fit and bound to the core with cotton tape before assembly of the porcelain and bottom washer. A section of heavy wall herkolite cylinder, with notches to engage supporting lugs extending from the I.D. of the bushing support, is attached to the outside of the core with an oil-proof adhesive after assembly of the bushing support. The notches in the cylinder engaging the support lugs prevent rotation of the core and provide axial support. These two methods of supporting the core insulation combined with the spotted adhesive, through-cut the wind, provide assurance that the core insulation will not slide or telescope.

TREAT

A large oven with vacuum facilities which could contain the complete bushing assembly is available. The complete bushing was heated and the insulation dried, by vacuum and dry air, in the oven. The temperatures inside the core tube, as well as oven temperatures, were measured and recorded throughout the period in the oven. The vacuums at the location of the vacuum connection to the bushing and at the opposite end of the bushing were measured and recorded. Power factor and capacitance, between capacitance tap and core tube, were measured with a low voltage bridge and recorded periodically throughout the treating process. The bushing was removed from the oven for the final fine vacuum and oil impregnation of the internal insulation. The power factor shown in the test data indicates the treat process is adequate.

TESTS

The bushing successfully withstood all the test voltages shown in Table I and demonstrated adequate margin between the stated withstand voltages and the actual maximum withstand voltages. Table II shows some of the maximum test voltages applied.

A summary of the total time sixty cycle voltages, 600 KV or greater, were applied and the number of times impulse voltages greater than 1900 KV were applied is shown in Table III. The longest single application of voltage was 15 minutes at 600 KV. Power factor and capacitance was checked between each series of tests and ultrasonic corona detection was used during some of the tests. 2

Later investigations have indicated that 2050 KV BIL is more nearly in line with the insulation class desired for the bushings to be used on Project EHV. The test results on this sample warranted this small increase in rating.

CONCLUSION

A bushing suitable for application at 2050 KV BIL has been built and tested. Additional test experience will be obtained on this size bushing through its use on Project EHV. The experience gained provides assurance that bushings for application on any voltage system, 2050 KV BIL or lower, can be built with existing materials and processes.

REFERENCES

1. Project EHV, P. A. Abetti, Electrical Engineering, Vol. 77, Aug. 1958, pp 669-673.

2. Ultrasonic Detection and Location of Electric Discharges in Insulation, J. G. Anderson, Power Apparatus and Systems, No. 27, Dec. 1956, pp 1193-1198.

APPENDIX

TABLE II

MAXIMUM VOLTAGES APPLIED

Negative Impulse	
2910 KV	Chopped Wave, 4 microseconds chop time
2570 KV	Full Wave, 2.2 x 50 microsecond
Positive Impulse	
2045 KV	Full Wave, 2.2 x 50 microsecond
60 Cycle Dry	
1115 KV	1 Minute, OK
1150 KV	20 Seconds--Flashover
60 Cycle Wet	
980 KV	Average Flashover

TABLE III

SUMMARY OF TESTS APPLIED

Impulse 1-1/2 x 40 Microsecond

(120) Full Waves 1925 KV to 2570 KV

60 Cycle Dry

1-1/2 hrs. at 600 KV, line to ground, approx. 15 min. at a time. 11 min., 700 KV to 1115 KV, line to ground, mostly 1 min. per test.

60 Cycle Wet

(15) Flashovers - 950 KV to 1035 KV

Power Factor and Capacitance at 200 KV

	Power Factor	Capacitance
Initial	0.45%	365 uuf
After Tests	0.44%	368 uuf

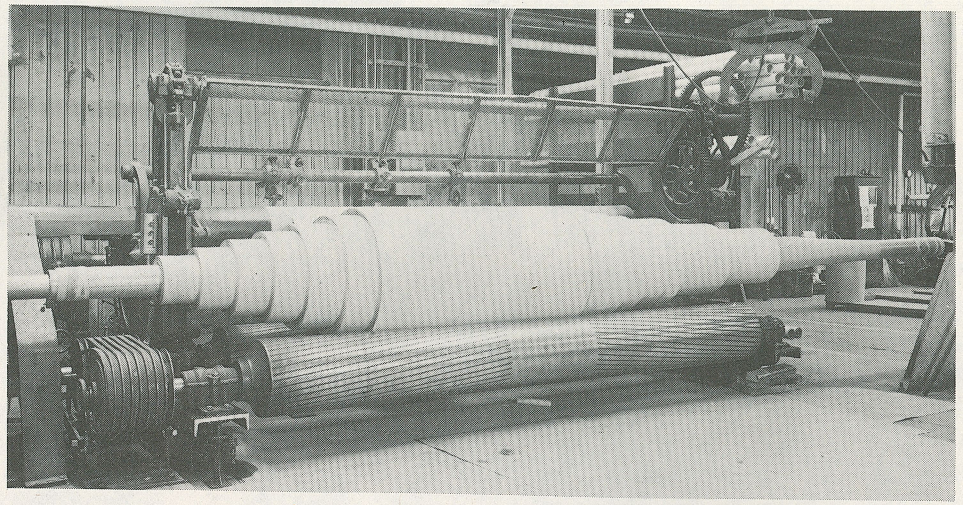

Fig. 1. Completed Core

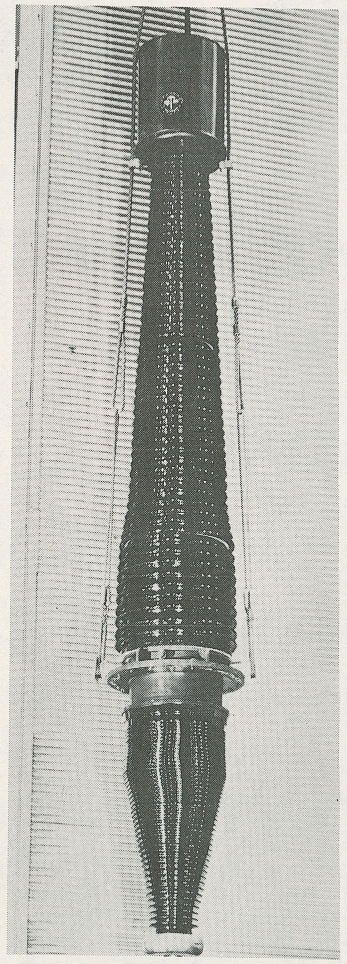

Fig. 2. 2050 KV BIL Transformer Bushing